HIGH-SPEED TIME-RESOLVED HOLOGRAPHY FOR IMAGING TRANSIENT EVENTS

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INTRODUCTION

A time-resolved holographic system was developed to study detonation dynamics in dispersed solid particulate explosives. This required a system capable of recording a rapid sequence of exposures during the approximate 1μs lifetime of the detonation event.

To investigate such transient phenomena where individual events are not identical, it is advantageous to study the entire duration of a single experiment. While this may be easily accomplished and is rather commonplace for pointwise detectors, e.g. interferometers, ultrasonic transducers, etc., the task becomes more difficult for full-field imaging techniques like holography. The difficulty in recording multiple holographic exposures of an event increases as the total lifetime of the event decreases. Although it is a simple task to record ten holograms of an event which lasts ten seconds, it is considerably more difficult to record ten holograms of an event which lasts only one microsecond. Obstacles such as holographic exposure multiplexing, timing, and beam steering must be overcome. Perhaps the greatest problem is generating the optical pulses necessary to record such fast phenomena. Typically, multiple Q-switching of a laser cavity does not permit optical pulses to be generated with pulse intervals less than 10 microseconds[1], and mode-locking a cavity generally results in low energy pulses at nanosecond intervals.

In an effort to study the detonation of single explosive particles with lifetimes of about 1 microsecond, a configuration for sequential holographic recording based on a new system for obtaining a train of spatially separated light pulses was developed. The multipulse system uses a single high energy Q-switched Nd:YAG laser pulse as a light source, and incorporates a phase-front preserving optical delay line and a specially graded beamsplitter to divide the initial pulse into ten spatially separated light pulses of nearly equal energy. The temporal spacing between successive output pulses may be varied discretely from 28.3ns to 169.8ns in steps of 28.3ns.

Using the time-resolved holographic system, it was possible to image the detonation process, specifically the generation and decay of a reaction volume, and the formation and propagation of a shock front. Measurements taken from the holographic images were used to obtain relationships for shock front extent, shock front velocity, and shock overpressure as a function of time after detonation. For example, it was found that initial shock velocities approaching Mach 9 decayed to near acoustic velocities (Mach 1.5) within 2μs[2]. In addition, the feasibility of using the time-resolved holographic system to investigate multiple particle interactions was demonstrated.

TIME-RESOLVED HOLOGRAPHIC SYSTEM

The heart of the time-resolved holographic system described here is a phase-front preserving optical delay line, or a "White cell"[3]. Originally developed for optical spectroscopy applications, the White cell is constructed with three spherical, concave mirrors of equal radii of curvature. The positioning of the mirrors relative to each other in order to obtain long optical paths is described in a previous paper, where the White cell was used for rapid double exposure holography, with exposure intervals ranging from 53ns to 426ns[4]. Once properly configured, the optical path through the cell may be varied by slightly adjusting two of the mirrors.

In the current system, the White cell is used in conjunction with a specially made beamsplitter to provide the desired optical output. In practice, a single high-energy Q-switched optical pulse is directed into the White cell. After exiting the cell, the light pulse is split by the beamsplitter. A small fraction of light passes through the beamsplitter and is used for the first holographic exposure. The majority of the light is reflected by the beamsplitter, which, in conjunction with a flat mirror, redirects the light back into the White cell at a slightly different elevation relative to its first pass. When this portion of light exits the cell a short time later, it is again sampled by the beamsplitter. Another portion of the light passes through the beamsplitter and is used to record the second holographic exposure, whereas the light which is reflected by the beamsplitter is again redirected into the White cell at yet another elevation. This process of optical delay followed by sampling at the beamsplitter is repeated up to ten times as the light spirals "down" the White cell to produce the desired number of exposures.

By using the beamsplitter/flat mirror combination to change the elevation of the each beam as it is redirected into the White cell, each successive pulse through the cell exits at a different elevation, hence each is split by a different portion of the beamsplitter (Figure 1). If an ordinary 50/50 beamsplitter were used, each successive output light pulse would contain progressively less energy. This is undesirable for the holographic recording and developing process. To compensate for this, a beamsplitter was designed which would produce ten output pulses of nearly equal energy given the initial high energy pulse which is continually recirculated through the White cell. The design takes into account losses within the White cell and the losses associated with the beamsplitter itself. To generate ten pulses of equal energy, the beamsplitter need incorporate ten sections of different reflectivity. From simple calculations, it was determined that the reflectivities of the first three beamsplitter sections should be within 2.5%. Owing to manufacturing tolerances, however, these were grouped into a single reflectivity section. The fourth and fifth beamsplitter sections were also grouped into a single reflectivity for the same reason. This resulted in a beamsplitter with seven separate reflectivity zones ranging from 0% to 95% for the most reflective section.

The output pulses from the White cell/beamsplitter assembly are collimated and propagate adjacent and parallel to each other. This facilitates separate control of each pulse. The time interval between output pulses is governed by the time-of-flight in the White cell. In the current system, each output pulse is split into object and reference beams. The object beams are arranged so that each interrogates the test volume at a slightly different angle, and therefore falls on a separate portion of the film plate. The reference beams are directed toward the film plate in such a manner as to minimize the variation in the object beam/reference beam angle as the exposures progress across the filmplate.

The current system uses a frequency-doubled pulsed Nd:YAG laser to produce an initial 300mJ light pulse of 9ns full-width-half-maximum duration. Each of the mirrors used in the White cell has a 2 meter radius of curvature, enabling framing intervals ranging from 28.3ns to 169.8ns in discrete steps of 28.3ns.

EXPERIMENT

The time-resolved holographic system described above was used to study shock front propagation and interaction in solid particulate explosives. Two 125μm diameter single particles of lead azide were suspended from two titanium-tipped electronic probe needles. The needles were positioned so that the particles were separated by approximately 250μm. A low energy pulsed Nd:YAG laser was used to detonate one of the particles. The ensuing explosion generated a propagating shock front and a small reaction volume comprised of the hot detonation products. Coincident with the detonation of the first particle, a single high energy Q-switched pulse was obtained from a high energy pulsed Nd:YAG laser and directed into the time-resolved holographic system.

For this particular experiment, the White cell was configured for a 113.2ns interval between output optical pulses. Nine vertically aligned output pulses were

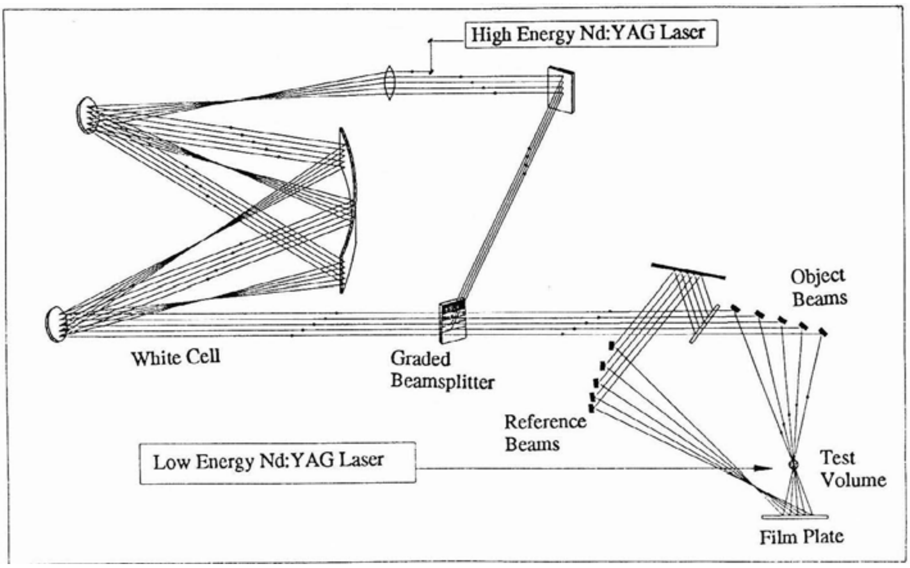

Figure 1. Schematic of the White cell/graded beamsplitter assembly used for generating spatially and temporally separated multiple optical pulses. The configuration illustrated uses three spots on the field mirror, and produces five output pulses.

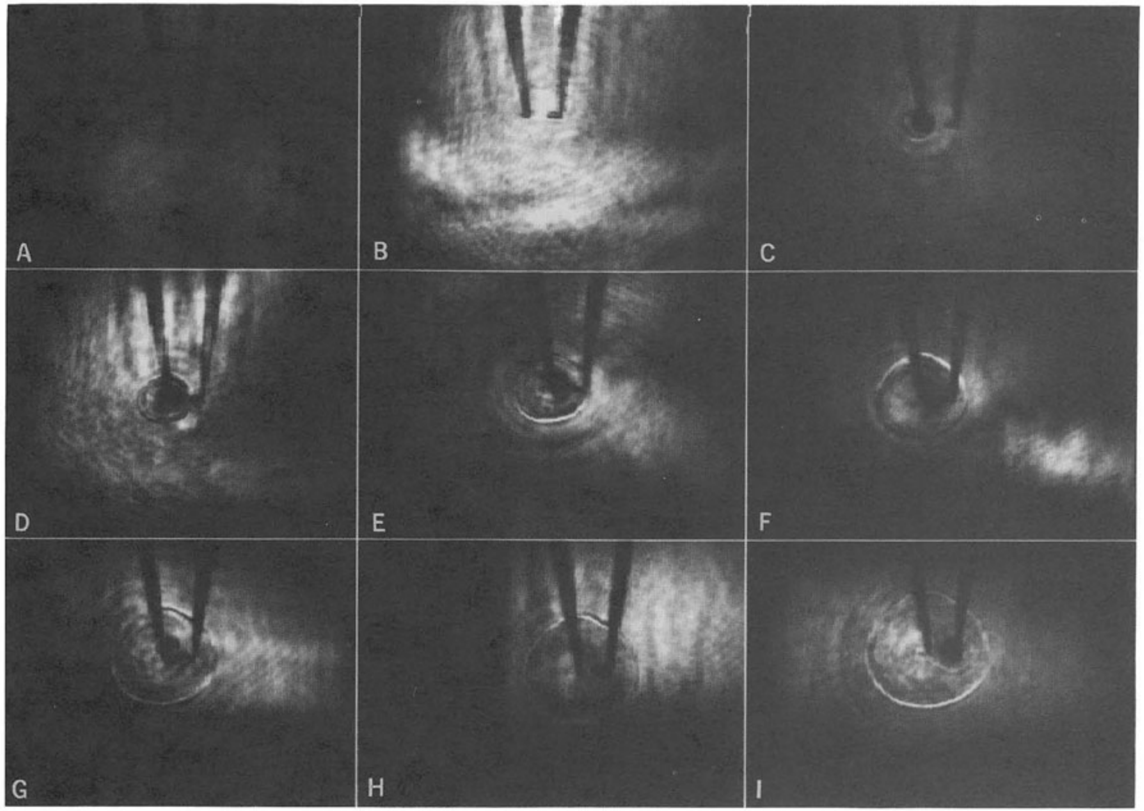

Figure 2. Reconstructed images of single particle detonation and the subsequent detonation of a second energetic particle. The time interval between exposures is 113.2ns.

obtained and rotated to horizontal with a right angle periscope. These pulses were then directed through a 50/50 beamsplitter to provide reference and object beams. The recording geometry was similar to that shown in Figure 1, except that each of the nine object beams was directed through an individual diverging lens to increase the interrogated test volume. It was possible to expand the reference beams with a single lens and steer them to the appropriate areas of the film plate.

Figures 2a-i show a time record of the detonation event. In Figures 2a and 2b no evidence of detonation can be observed. However, Figure 2c shows that detonation has begun in the first particle. The shock front is visible as a thin line surrounding the left needle tip, and the dark reaction volume can also be observed. Figures 2d and 2e show the shock front moving outward and the reaction volume growing. In Figure 2f, the shock front has already passed the second particle, and the reaction volume seems to have just touched it. Figures 2g and 2h continue to show the propagation of the shock front, and the decay of the reaction volume. Finally, Figure 2i shows that the second particle has begun to detonate, and is in a stage of detonation similar to that of the first particle in Figure 2c.

Presently, work will be performed to more closely examine the interaction mechanisms between these single energetic particles during detonation. This will be accomplished by decreasing the exposure interval, and investigating separate stages of the detonation event. Additionally, the system is being used to study crack propagation in brittle films.

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